Sound-Based Technologies and Strategies Used for Community Mobility by Adults with Vision Disability

Technical Report TechSAge-TR-1904
Atlanta, GA: Georgia Institute of Technology
Rehabilitation Engineering Research Center on Technologies to Support Successful Aging with Disability (RERC TechSAge)
(www.rerctechsage.org)

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2019

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Suggested Citation: Bruce, C. and Echt, K. (2019). *Sound-Based Technologies and Strategies Used for Community Mobility by Adults with Vision Disability***.** (TechSAge-TR-1904). Atlanta, GA: Georgia Institute of Technology, Rehabilitation Engineering Research Center on Technologies to Support Successful Aging with Disability.

Acknowledgements

This research was supported in part by a grant from the National Institute on Disability and Rehabilitation Research (Department of Education) Grant H133E130037 under the auspices of the Rehabilitation and Engineering Research Center on Technologies to Support Successful Aging with Disability (TechSAge; www.rerctechsage.org). The contents of this technical report were developed under a grant from the Department of Education. However, those contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.

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1. Introduction

Individuals aging with vision disability, who bear greater comorbidity burden, may experience considerable negative secondary impacts on mobility activity and participation (e.g., (Crews & Campbell, 2004; Ray, Horvat, Williams, & Blasch, 2007)) than either older adults without disabilities or younger individuals with disabilities. For individuals with visual disability and age-related hearing loss (e.g., presbycusis, changes in sound discrimination abilities), negative outcomes can be attributed to diminished effectiveness of sound-based compensatory strategies (e.g., auditory spatial cues), assistive technology (AT) (e.g., sonic canes, talking GPS), and public technologies (e.g., crosswalks).

Mobility limitations affect as many as one half of older adults (Webber, Porter, & Menec, 2010) and result in significant disability risk (Rosso, Taylor, Tabb, & Michael, 2013). Identifying those factors that hinder the independent mobility of older people is critical for informing rehabilitation approaches that optimize engagement and independence in everyday life (Rantanen et al., 2012). Vision impairment is an increasingly prevalent source of disability in the United States that can dramatically affects a person's capacity for interaction with the physical environment (*mobility).* Evidence suggests that people with vision impairment have deficits in ambulation (e.g., gait speed, balance), increased rates of inactivity and participation restrictions that may account for higher rates of obesity, and greater comorbidity burden relative to non-visually impaired comparisons (e.g., (Loprinzi, Smith, & Pariser, 2013; Ray et al., 2007)). Conversely, hearing loss affects nearly 67% of persons aged 70 or older (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011) and results in a greater likelihood of social isolation and increased burden of disease and limitations in physical function (Genther, Frick, Chen, Betz, & Lin, 2013). Concomitant hearing and vision impairment, moreover, increases in prevalence with age; as many as 22% of adults age 70 and older are affected (Jee et al., 2005). It is expected that hearing loss associated with aging will further limit the mobility, range of activity, and community participation of visually-impaired persons by constraining options for compensatory device and/or strategy use. Studies to evaluate the impacts of hearing loss are timely, given emerging evidence regarding the adverse outcomes of co-occurring vision and hearing impairment (Gopinath B et al., 2013).

Rehabilitation approaches commonly harness hearing (e.g., auditory spatial localization, talking AT) to foster adaptation to and compensation for mobility limitations consequent to impaired visual function. Spatial navigation and wayfinding are supported via AT (e.g., sonic cane, talking GPS). Yet, successful adoption and continued utilization of AT assumes intact auditory function. Design and evaluation research on audio-based mobility AT has not considered the influence of hearing loss on performance (e.g., Loomis, 2003; Ross & Lightman, 2005; Ross, Lightman, & Henderson, 2005). Furthermore, while studies have demonstrated that mobility performance with AT is contingent on the fit of device and user (Rodgers & Emerson, 2005), studies to evaluate how such fit changes over time are scarce. The impact of secondary hearing impairments on the continued use and usability of AT by visually impaired adults over age 65 years is not known. The consequent effects of hearing impairment on visually impaired persons' mobility activity and participation, moreover, has not been studied.

Aging occurs in the context of multiple comorbidities (American Geriatrics Society Expert Panel on the Care of Older Adults with Multimorbidity, 2012), however both research and rehabilitation practice have traditionally addressed comorbid conditions in sequential, fragmented manner. The reality that vision and hearing loss frequently co-occur, and yet are separately addressed by specialty-trained rehabilitation professionals and AT designers who lack multisensory integrative training is a significant barrier to successful outcomes (Roh, Kim, Paik, Kim, & Gong, 2012; Saunders & Echt, 2007). It is clear that rehabilitation providers and AT designers lack evidence-based guidance and even basic descriptive evidence for informing integrated rehabilitation practices, prescription for rehab interventions, and design of AT devices that account for comorbid conditions and consequent activity limitations and participation restrictions in older adults with vision disability (Saunders & Echt, 2007; Swenor, Ramulu, Willis, Friedman, & Lin, 2013).

2. Purpose

Evidence-based design is crucial to developing effective technologies to support community mobility for adults aging with vision impairment and age-related hearing changes. However, there is limited information about the use, usefulness, and usability of sound-based compensatory strategies and technologies by older adults with vision impairment and the effects of secondary hearing impairments. The overarching hypothesis is that older adults with vision disability and age-related hearing changes experience mobility limitations due to diminished use (manner and frequency of use), usability (effectiveness, efficiency, satisfaction), and usefulness (helpfulness in completing tasks and fulfilling goals/motivations, and value in specific situations) of sound-based compensatory strategies and technologies. The focal hypothesis for this investigation is that self-reported usefulness and use frequency of technologies (personal and public) and compensatory strategies used for community mobility will be lower among individuals with vision impairment and age-acquired hearing change compared to individuals with vision impairment alone.

This investigation specifically examined adults' self-reported use and usefulness of technologies (personal and public) and compensatory strategies for community mobility. The first study consisted of interviews with older adults to establish an awareness of reported sound-based technology and strategy practices, and observe mobility behaviors in context. These interviews helped inform a survey that was sent to a broader audience of younger and older adults to get further details about technologies and strategies used, problems experienced during community mobility, and suggestions for technology improvements. Our third study was a set of interviews focused on understanding the concept of confidence as it relates to community mobility and the supporting role that technologies and strategies play.

3. Study 1: Interviews on Sound-Related Issues

In-person interviews were conducted with older adults who had vision impairments and age-related hearing changes to establish a baseline understanding of the role of sound in community mobility. We targeted their experiences with listening strategies and technologies with sound-based features when moving around in outdoor public spaces. These interviews were approved through the Georgia Tech Institutional Review Board prior to the start of the work.

3.1 Methods

3.1.1 Participants

Five adults (3 male and 2 female) with self-reported long-standing vision impairment (>10 years) and hearing loss participated in this study (Age range: 41-68 years; Mean age: 52 years). To be eligible for this study, participants had to be fluent in English, be age 18 years or older, have had a vision impairment for at least five years, experience minor hearing difficulty, and use sound-based compensatory strategies and technologies to independently get around in their communities multiple times during the week. Eligible participants were screened by phone prior to selection to ensure that they met study criteria. Screening questions included brief details about duration of vision impairment, personal and public sound-based technology use during community mobility, and reported issues with hearing.

3.1.2 Materials

The Interview Guide was internally created to guide researchers through a semi-structured interview. Questions were constrained to an individual's experiences during community mobility activity and grouped according to use of: 1) personal technologies; 2) public technologies; and 3) compensatory listening strategies. Each set of questions addressed details about the technologies or compensatory strategies reportedly used including the manner of technology use (e.g., use of headphones/earphones/bonephones/speaker, carried/worn), effectiveness of the strategy or technology's features for specific orientation and mobility situations, and environmental conditions that impact use and usability.

3.1.3 Procedures

Participants received the study consent document via email prior to the in-person study meeting so they could review it according to their visual needs and prepare any questions. At the start of each study session, the participant and researcher met at a local organization that serves people with vision impairments. Before the start of the study session, the researcher reviewed the consent document with the participant and answered questions before requesting their signature. After consenting, a researcher screened the participant's hearing using headphones and a portable pure-tone audiometer across a range of common speech and non-speech frequencies (250, 500, 1,000, 2,000, 4,000, 6,000, 8,000 Hz) to determine whether more than a mild hearing loss was indicated (hearing threshold worse than 40 dB). The researcher interviewed the participant and then, followed him/her out of the building to observe outdoor mobility behaviors and discuss related issues.

3.1.4 Data Preparation

The researcher took notes during the interviews and outdoor observation and discussion. Audio recordings of the interviews were uploaded to a computer and reviewed for further annotation to highlight important statements or points to be examined later. The notes and related annotations were analyzed based on an open coding content analysis that was partly guided by the researcher’s knowledge of the literature, questions asked during the interviews, and annotation during the transcription phase. The codes and related excerpts were then grouped into broader categories of data themes.

3.2 Results

3.2.1 Environmental Auditory Features and Acoustics

Ambient sounds and space acoustics impact mobility activities in positive and negative ways and thus, have perceived value along the spectrum of usefulness. During the interviews and outdoor discussions, participants commented on the usefulness of various environmental sounds and acoustic characteristics of public outdoor settings. Vehicle traffic, construction, and weather sounds were consistently described as not useful because they overpowered or interrupted the more useful sounds such as cane taps and crosswalk tones (beeps, chirps). Participants referred to traffic sounds mostly as the noise of vehicles (cars, buses, trucks, motorcycles) driving past, but some also mentioned their annoyance with loud music coming out of vehicle windows or pulsing through the vehicle body. Three of the participants specifically talked about how hard it was to hear the crosswalk sounds when vehicle traffic was heavier. One of them also pointed out that traffic noises are sometimes useful if he is trying to understand when he might attempt to cross a street when there is not a crosswalk with sound output. The absence of sound from vehicles -- quieter vehicles such as bicycles and electric cars -- was also seen as a problem. Problems with construction sounds were noted by all participants and included machinery noise (e.g., jack hammers or engines) and alerts. Weather issues included the noise from rain landing on surfaces and from vehicles driving through it, gusts of wind carrying sounds away, wet surfaces changing the quality of useful sounds (cane taps can be harder to hear), and thunder interfering with useful sounds. One participant mentioned that the noise of people getting on or off the MARTA train can make it hard to hear the train and station messages. Participants descriptions about the more useful environmental sounds largely focused on sounds that served as familiar cues for location (e.g., automatic doors opening at a grocery store, children at the playground).

3.2.2 Smart Phones

Despite the myriad of specialized and built-in smartphone apps and functionality to aid mobility, the participants all reported that they infrequently use their phones to help them navigate public spaces. For some, their lack of use was because they were afraid they would drop the phone while walking or that it would make it hard to use their hands for something else (e.g., open doors or use their white cane). When asked about using headphones or earphones to free their hands, most said they would prefer not to cover their ear because they rely on hearing other sounds around them for mobility and safety. One participant who used earphones said that she had a hard time hearing her phone with them and that she constantly adjusted the volume. Most reported that they had focused on learning to use the basic features of their phones (e.g., phone calls, email). None of them could name an app that was useful to them for mobility purposes.

3.2.3 Assistive Technologies for Mobility

Similar to smartphones, there are numerous specialized or assistive technologies to assist individuals with vision impairment in community mobility. These technologies typically include the traditional options such as white canes, sonar devices, and GPS systems, as well as newer technologies including those that leverage computer vision to sonify or describe the visual scene. Guide dogs or other service animals may also be considered assistive technologies, although this classification is less common. All of our participants used a white cane as their primary assistive technology for community mobility. White cane techniques varied among the participants, but all said they relied on listening for the sounds resulting from their cane movements. When they could not hear the sounds, they would get frustrated and feel less confident. Some had tried other assistive technologies as a one-time occurrence or for trial periods, but none had decided to use anything other than their white cane on a regular basis. Reasons they gave for not using other assistive technologies included that some devices were too costly to purchase or repair, some were too complicated to learn how to use or use efficiently, and they preferred something that felt reliable and could be used almost anywhere.

3.2.4 Public Technologies

Public technologies such as crosswalks with sound output and talking kiosks at trains, bus, or subway stations are important to independent community mobility. Participants described their prior use of these technologies and we observed them in action at crosswalks in the nearby area and with the talking kiosk at the closest MARTA station. Crosswalks with tones or spoken messages were reportedly useful most of the time. Participants felt more confident at intersections with crosswalk sound output compared to those without. They reported that being able to hear these sounds was important and interference from other environmental sounds was frustrating and made the sounds less usable. Poor usability of the sounds resulted from design issues and/or the participant's hearing loss. Participants complained about the unclear spoken street names at crosswalks and confusing or inconsistent crosswalk tones. Several conceded that their hearing might be a reason that the sounds were less effective for them. Only two of the participants had used the MARTA kiosk before and one of them didn't know that the kiosk had a talking interface because he had relied on the Braille and other tactile markings for his previous transactions. As we observed the participants using the kiosk, each one had difficulties that required the researcher to intervene or explain what went wrong. All of the participants mentioned that they felt like there was missing or confusing information from the talking MARTA kiosk.

3.3 Discussion

The interviews revealed that older adults who are aging with vision impairment and age-related hearing changes use a variety of sound-based technologies and strategies to navigate in outdoor settings. The rely mostly on listening for sounds and do not often use smartphones for mobility purposes. Hearing changes can have an effect, but it isn't always easy for an individual to recognize determine by themselves whether the cause of their usability problems are merely a result of their hearing loss or

4. Study 2: Survey on Methods Used

The findings from the interviews informed a survey that focused on the problems that people with vision impairment face when using compensatory listening strategies and sound-based technology features to support orientation and mobility in public spaces. This survey validated issues mentioned by interviewees as well as gathered data from a larger, geographically diverse sample. This survey was approved through the Georgia Tech Institutional Review Board prior to the start of the work.

4.1 Method

4.1.1 Participants

To be eligible for this study, participants had to be fluent in English, be age 18 or older, have had a vision impairment for at least five years, and use sound-based compensatory strategies and technologies to independently get around in their communities multiple times during the week. Ninety adults (43 male; 47 female) who had self-reported vision impairment (>5 years) participated in this study. The majority of respondents (n=64) were over 50 years of age. The age group with the greatest portion of respondents was 60-64 years, representing 23% of the total.

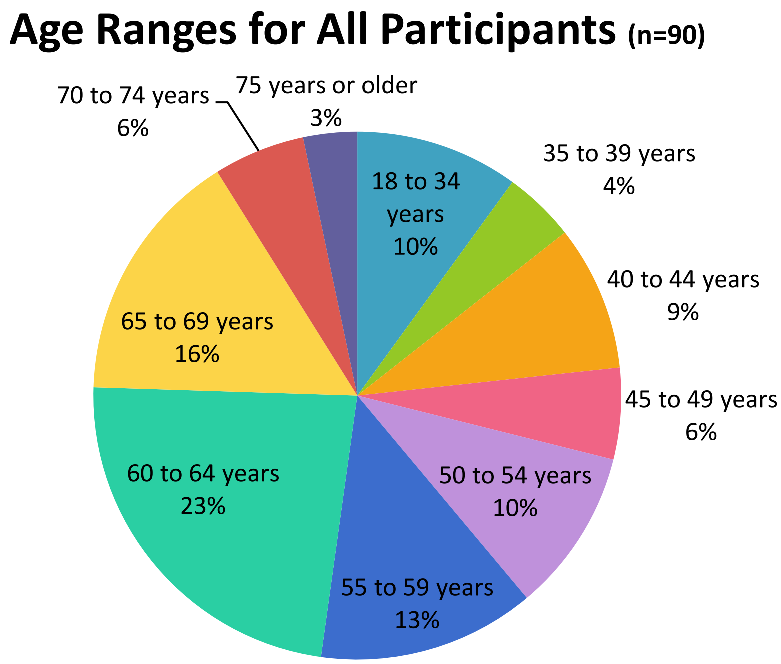


Figure 1. Participant Age Ranges.

The overall sample was predominantly Caucasian (79 percent), followed by 6 percent identifying as “other”, 4 percent as African American, 2 percent as more than one race, and the remaining participants (9 percent) choosing not answer. For older adults (>50 years of age), 84 percent indicated their primary racial group as Caucasian, 6 percent as “other”, 2 percent as more than one race, and 8 percent choosing not answer. For younger adults (18-49 years of age), 65 percent identified their primary racial group as Caucasian, 15 percent as African American, 4 percent as more than one race, 4 percent as “other”, and 12 percent choosing not to answer. Only 2 percent of respondents reported being Hispanic or Latino as part of the older adult group.

Participants were recruited through advertisements sent to organizations that provide services to people who have vision impairment or conduct research in relevant areas. These recruitment efforts were scheduled in three waves to enable periodic data reviews. The initial wave focused on Georgia-based and national organizations including the American Council of the Blind, American Foundation for the Blind (and the Georgia chapter), Blind Veterans of America, Center for the Visually Impaired in Atlanta, Georgia's Tools for Life, National Federation of the Blind (and the Georgia chapter), National Research and Training Center on Blindness and Low Vision, and Older Individuals who are Blind Assistance Center. The remaining two waves targeted over 50 state-based organizations outside of Georgia for blind or low vision services, centers for independent living, area agencies for aging or disabled adults, radio reading services, and assistive technology programs. It is unclear how many of these state-level organizations marketed the study advertisement because they were not required to confirm receipt nor indicate their intention in advertising. Organizations from Alabama, Arkansas, Arizona, California, Colorado, Georgia, Maryland, Mississippi, and North Carolina reported to us that they sent study information via electronic and paper newsletters, radio broadcasts, emails, listservs, and website announcements.

4.1.2 Materials

The survey collected information about vision ability, hearing ability, technology and strategy use, and demographics. The initial survey questions about vision ability, duration of vision impairment, age, frequency of outdoor community travel, and hearing ability helped to qualify potential respondents for the survey. Responses that would disqualify a respondent include: 1) able to see without difficulty; 2) less than 5 years of vision impairment; 3) younger than 18 years of age; 4) less than 1 independent trip per week into the community; and 5) hearing ability is profound difficulty or deaf.

SurveyGizmo, an online tool for creating web and mobile surveys, was used to deliver the survey based on its support for designing surveys to be accessible for screen readers, high contrast, and magnification. Prior to deployment, we tested the survey with several combinations of browsers, operating systems, and screen readers to minimize accessibility and usability issues.

4.1.3 Procedures

The first version of the survey was deployed online in March 2017 and collected data until May 2017. During that time, 66 survey attempts were logged as a result of the first wave of recruiting. There were 49 completed surveys, 13 partial surveys (participant did not answer questions about technology or strategy use), and six surveys with disqualified responses. In June 2017, additional questions about hearing abilities were added based on feedback from a project advisory board meeting. The survey was redeployed and a second wave of recruiting yielded 56 new survey attempts; 39 were completed surveys, six were partial, and 10 were disqualified. A final wave of recruiting occurred in October 2017, yielding an additional two completed surveys, one partial survey, and one disqualified. The survey closed in December 2017 with 90 completed surveys that were included for analysis and 36 that were excluded based on incomplete or disqualified responses.

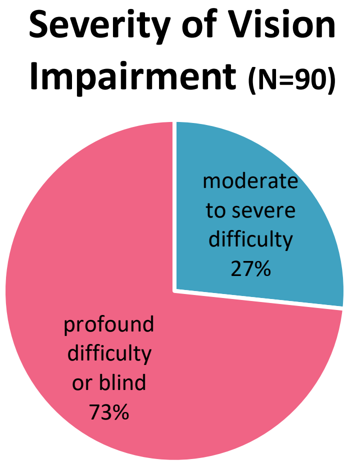
4.2 Results

4.2.1 Educational Level

Respondents all had at least a high school diploma or GED. A majority (96%) had vocational training or some college-level education, with seventy-three percent of respondents (n=66) reported having a Bachelor’s degree or higher. There was an even distribution between Master’s and Bachelor’s degrees (n=30) and a small number of Doctoral degree recipients (n=6). Higher levels of education were seen in the older adult group (>50 years of age) with almost half holding a graduate degree (n=29), compared to a majority (73%) of their younger counterparts (18-49 years of age) who reported Bachelor-level or lower educational training.

4.2.2 Vision

We asked participants to indicate their vision ability and the duration of their difficulty seeing. For vision ability, there were given four choices: “able to see without difficulty”, “able to see with only minor difficulty”, “moderate to severe difficulty or low vision”, and “profound difficulty or blind”. If a participant was “able to see without difficulty”, they were disqualified from taking the survey. None of the participants indicated a minor difficulty seeing. A majority of respondents (73 percent) identified as having a profound difficulty or being blind, and the other 27 percent indicated they had moderate to severe difficulty or low vision. This distribution was identical for both older and younger adult groups. These findings were not surprising given that we had targeted people who relied on technology or other compensatory strategies to get around in the community. When asked about the duration of their vision impairment, participants indicated the length of time of difficulty based on the following options: “less than 5 years”, “5 to 7 years”, “7 to 9 years”, “10 to 12 years”, “13 to 15 years”, or “more than 15 years”. Participants who had less than five years difficulty were disqualified from the survey. All participants reported seven or more years of difficulty seeing and 92 percent had difficulty for more than 15 years. In the older adult group, all participants had at least 10 years of vision impairment, with a majority reporting greater than 15 years. Younger adults also had a high percentage (85 percent) indicating over 15 years with vision difficulty.



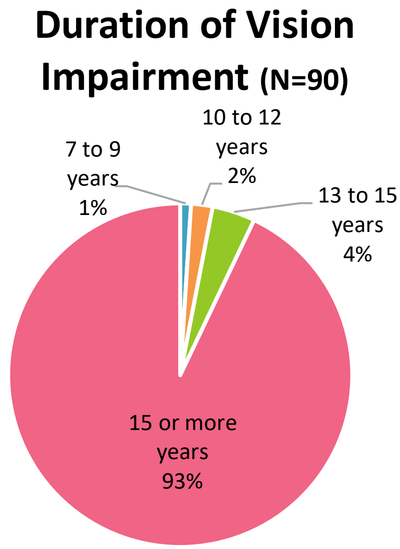


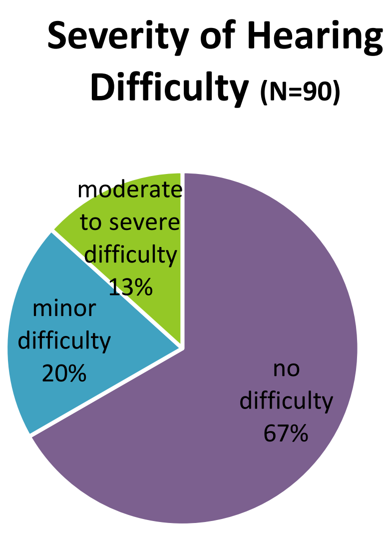
Figure 2. Severity and Duration of Vision Impairment for Participants.

4.2.3 Hearing

Participants were asked about their hearing ability including reported level of difficulty overall and in specific scenarios, belief that their difficulty is association with aging, duration of hearing difficulty, and use of devices to help with hearing. The initial question on hearing ability asked participants to indicate their hearing ability according to: “able to hear without difficulty”, “able to hear with only minor difficulty”, “moderate to severe difficulty hearing or hard of hearing”, and “profound difficulty or deaf”. Participants who chose “profound difficulty or deaf” were disqualified from taking the survey. Over half the participants indicated that they had no difficulty hearing (n=60). The remaining participants reported minor difficulty (20 percent) or moderate to severe difficulty (13 percent). Age-related differences were observed for level of hearing difficulty. Thirty-nine percent of older adults had some difficulty hearing compared to

20 percent of younger adults, and twice as many older adults (16 percent compared to 7 percent) reported a moderate to severe difficulty.

Participants who indicated a minor hearing difficulty or worse were asked follow up questions to further describe their hearing difficulties. The duration of hearing difficulty was spread across a range from less than a year (3 percent), 1 to 3 years (28 percent), four to six years (17 percent), seven to nine years (10 percent), and 10 years or longer (41 percent). Slightly over forty percent reported their hearing difficulty had persisted for 10 years or longer. Only one of the five younger adults reported having their hearing difficulty for less than 10 years (i.e., 4-6 years). Whereas a majority of the older adults with hearing difficulty reported duration of less than 10 years (n=16; 67 percent).



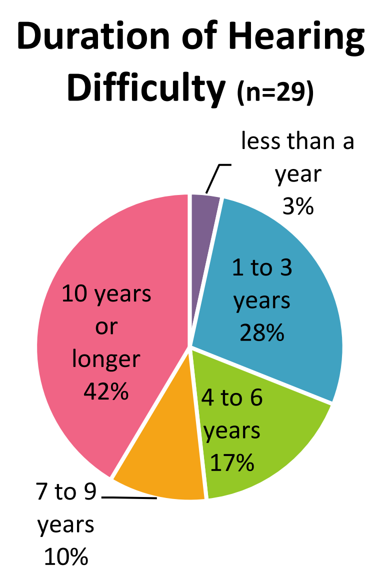


Figure 3. Severity and Duration of Hearing Difficulty for Participants.

When asked about whether they thought their hearing difficulty was related to getting older, only 28 of the 30 participants responded. Forty-six percent said it was caused by something else, 43 percent thought it was related to aging, and 11 percent were not sure if it was related. Most of the respondents for this question were older adults (n=23) and almost half of them thought their difficulty was related to aging (48 percent). The other older adults said their difficulty was caused by something else (39 percent) or that they were not sure if it was related to aging (13 percent). Within the younger adults, only one out of five thought their difficulty was associated with aging and the other four thought that it was caused by something else.

Of the 30 participants who reported a hearing difficulty, 50 percent said they did not use a device to assist with hearing, 43 percent used a hearing aid in both ears, and 2 percent did not answer this question. All participants in the moderate to severe difficulty hearing group (n=11) reported having hearing aids. In the group of participants with minor difficulties (n=17), only two responded that they had hearing aids. This prevalence of hearing aid ownership is higher than national statistics (https://www.nidcd.nih.gov/health/statistics/use-hearing-aids-adults-hearing-loss) that suggest for people who could benefit from hearing aids, only about 16 percent of adults aged 20-69 and 30 percent aged 70 and older had tried them. This raises the question of whether individuals who have comorbid hearing and vision issues are more likely to rely on hearing assistance than those with only one of these issues.

Participants were also asked to describe their level of hearing difficulty in three specific contexts: during phone conversations, watching television, and during conversations in restaurants. If they had previously indicated that they used an assistive device for hearing (n=6), they were asked to respond to the questions including the use of their “hearing aid or other listening device.” These questions were added to the survey after the first wave of recruiting, so only a portion of the survey participants responded to them (n=38).

For individuals who responded that they did not use a hearing aid or other listening device, a majority reported that they had no difficulty hearing across the three contexts. All participants found that conversations in restaurants were the most problematic, with 42 percent having at least occasional difficulty. Compare this to only 29 percent reporting difficulty during phone calls and 26 percent while watching TV.

Context	No Difficulty		Occasional Difficulty		Frequent Difficulty		Severe/ Cannot Hear		Total Count
	Percent	Count	Percent	Count	Percent	Count	Percent	Count	
Phone No Aid	81.3%	26	18.8%	6	0	0	0	0	32
Phone with Aid	16.7%	1	66.7%	4	16.7%	1	0	0	6
TV No Aid	84.4%	27	12.5%	4	3.1%	1	0	0	32
TV with Aid	16.7%	1	66.7%	4	16.7%	1	0	0	6
Restaurant No Aid	68.8%	22	25.0%	8	6.3%	2	0	0	32
Restaurant with Aid	0	0	33.3%	2	50.0%	3	16.7%	1	6

Table 1. Reported Context-Specific Hearing Difficulties.

As expected, participants reported having greater difficulty hearing in restaurants compared to watching TV or having a phone conversation. This is likely due to the limited amount of control that people have in minimizing or eliminating background noise in public places, or increasing the loudness of their conversational partner (phones and TVs have adjustable volume controls). Restaurants are also settings that enable the "Cocktail Party Effect". This means that there is a complex auditory scene that can make it difficult for people to tune out background noise while focusing on a specific sound stream such as a conversation. As age-related hearing changes occur, it becomes more difficult for a person to attend to and comprehend sounds of interest when background noise is present.

4.2.4 Mobility Activity Frequency and Personal Factors

We asked participants about the frequency of independent travel into their communities as part of understanding the relationship between mobility activity and other factors such as disability/impairment, gender, age, and technology and strategy use. Respondents who replied that they traveled less than two to three days per week were disqualified from the remainder of the survey based on the study exclusion criteria. Overall, a majority of participants (82 percent) said they get out in their communities four or more days per week without the assistance of another person. There was not a marked difference between the activity frequency of younger adults (85 percent) compared to older adults (82 percent) or males (79 percent) compared to females (85 percent). These high percentages were not unexpected due to study exclusion criteria and recruitment messaging that stated we were looking for adults who “use sound output technologies to independently get around in their communities multiple times during a week.”

Mobility Activity Frequency	***Age Range***										***Total***
	18-34	*35-39*	*40-44*	*45-49*	*50-54*	*55-59*	*60-64*	*65-69*	*70-74*	*>75*	
2-3 days per week	3.00	0	1.00	0	1.00	1.00	3.00	4.00	2.00	1.00	16.00
	18.75%	0%	6.25%	0%	6.25%	6.25%	18.75%	25.00%	12.50%	6.25%	100%
	33.33%	0%	12.50%	0%	11.11%	8.33%	14.29%	28.57%	40.00%	33.33%	17.78%
	3.33%	0%	1.11%	0%	1.11%	1.11%	3.33%	4.44%	2.22%	1.11%	17.78%
4-6 days per week	3.00	3.00	2.00	3.00	5.00	3.00	10.00	4.00	1.00	1.00	35.00
	8.57%	8.57%	5.71%	8.57%	14.29%	8.57%	28.57%	11.43%	2.86%	2.86%	100%
	33.33%	75.00%	25.00%	60.00%	55.56%	25.00%	47.62%	28.57%	20.00%	33.33%	38.89%
	3.33%	3.33%	2.22%	3.33%	5.56%	3.33%	11.11%	4.44%	1.11%	1.11%	38.89%
Every day	3.00	1.00	5.00	2.00	3.00	8.00	8.00	6.00	2.00	1.00	39.00
	7.69%	2.56%	12.82%	5.13%	7.69%	20.51%	20.51%	15.38%	5.13%	2.56%	100%
	33.33%	25.00%	62.50%	40.00%	33.33%	66.67%	38.10%	42.86%	40.00%	33.33%	43.33%
	3.33%	1.11%	5.56%	2.22%	3.33%	8.89%	8.89%	6.67%	2.22%	1.11%	43.33%
Total	9.00	4.00	8.00	5.00	9.00	12.00	21.00	14.00	5.00	3.00	90.00
	10.00%	4.44%	8.89%	5.56%	10.00%	13.33%	23.33%	15.56%	5.56%	3.33%	100%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	10.00%	4.44%	8.89%	5.56%	10.00%	13.33%	23.33%	15.56%	5.56%	3.33%	100%

Table 2. Association between mobility activity frequency and age range. Numbers in columns represent count, row %, column %, total %.

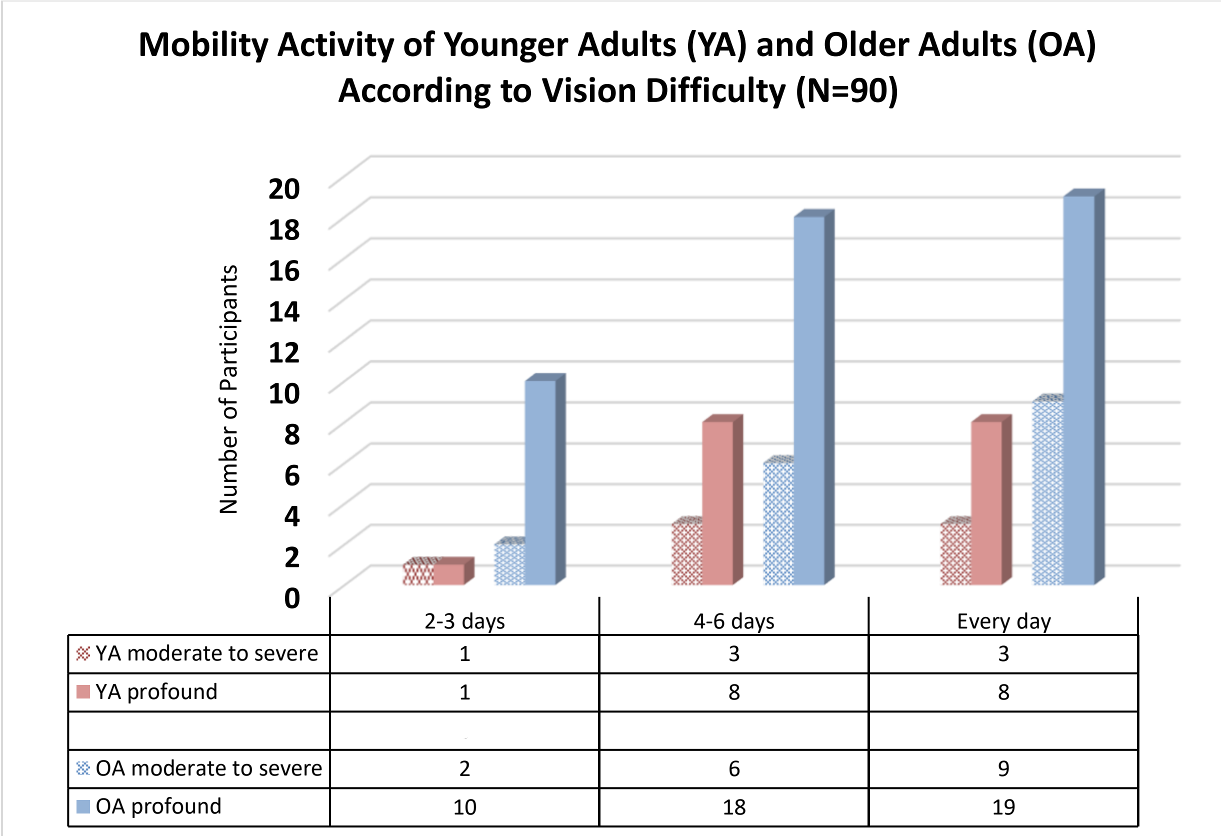
Mobility Activity Frequency	*Gender*		**Total**
	Male	*Female*	
2-3 days per week	9.00	7.00	16.00
	56.25%	43.75%	100%
	20.93%	14.89%	17.78%
	10.00%	7.78%	17.78%
4-6 days per week	13.00	22.00	35.00
	37.14%	62.86%	100%
	30.23%	46.81%	38.89%
	14.44%	24.44%	38.89%
Every day	21.00	18.00	39.00
	53.85%	46.15%	100%
	48.84%	38.30%	43.33%
	23.33%	20.00%	43.33%
Total	43.00	47.00	90.00
	47.78%	52.22%	100%
	100%	100%	100%
	47.78%	52.22%	100%

Table 3. Association between mobility activity frequency and gender. Numbers in columns represent count, row %, column %, total %.

Analysis of the impact of vision difficulty on reported frequency of mobility activity showed no statistically significant association between these two variables. The data suggests that level of vision impairment does not have an adverse effect on the frequency of community travel for the survey respondents. For participants who had profound vision difficulty or were blind, 41 percent (n=27) traveled independently into their communities every day. Half of the participants (n=12) with moderate to severe vision difficulty or low vision were also getting out on a daily basis. There were no notable differences in the impact of vision difficulty on mobility activity frequency when comparing the older and younger adult groups.

Mobility Activity Frequency	***Vision Function Level***		***Total***
	moderate to severe difficulty/ low vision	*profound difficulty/ blind*	
2-3 days per week	3.00	13.00	16.00
	18.75%	81.25%	100%
	12.50%	19.70%	17.78%
	3.33%	14.44%	17.78%
4-6 days per week	9.00	26.00	35.00
	25.71%	74.29%	100%
	37.50%	39.39%	38.89%
	10.00%	28.89%	38.89%
Every day	12.00	27.00	39.00
	30.77%	69.23%	100%
	50.00%	40.91%	43.33%
	13.33%	30.00%	43.33%
Total	24.00	66.00	90.00
	26.67%	73.33%	100%
	100%	100 %	100%
	26.67%	73.33%	100%

Table 4. Association between mobility activity frequency and reported vision function level. Numbers in columns represent count, row %, column %, total %.



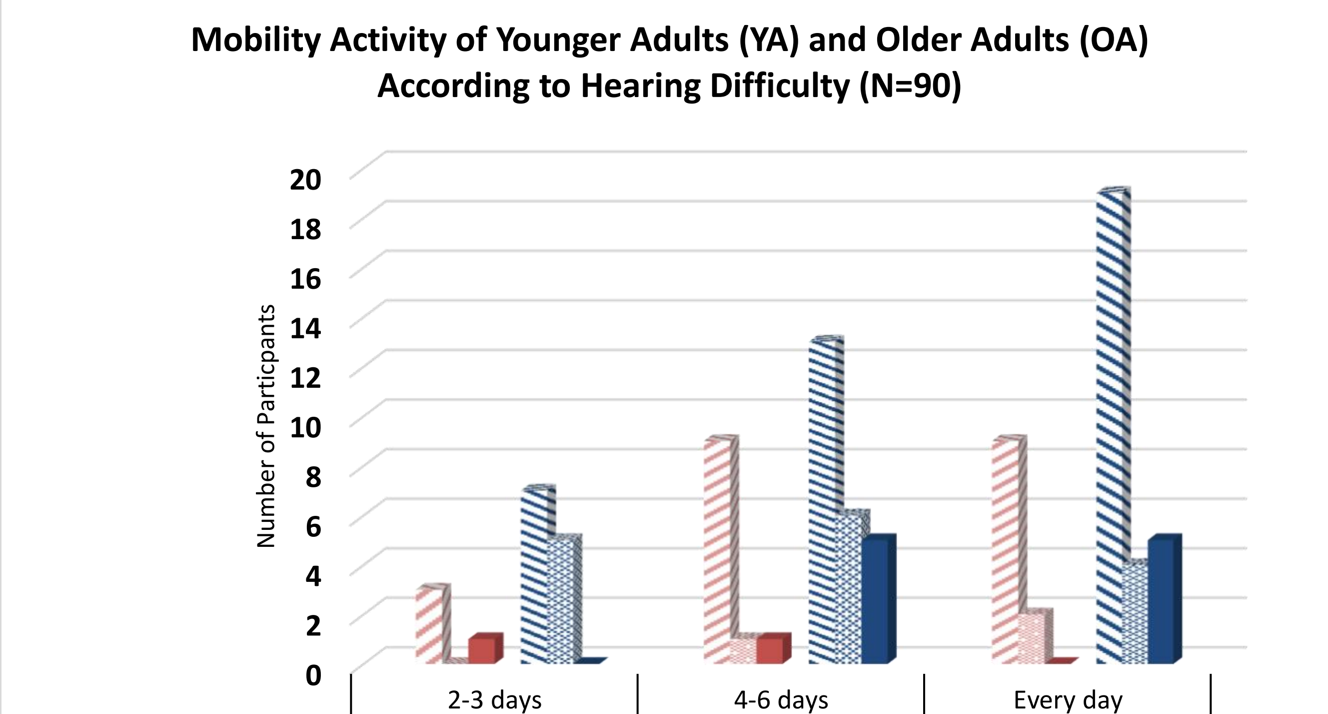
	2-3 days	4-6 days	Every day
YA moderate to severe	1	3	3
YA profound	1	8	8
OA moderate to severe	2	6	9
OA profound	10	18	19

Figure 4. Mobility activity frequency according to vision difficulty.

The relationship between hearing difficulty and mobility activity was also not statistically significant. Hearing loss did not appear to have a negative impact on survey participants' frequency of community outings. Although a majority of the participants who went out on a daily basis had no difficulty hearing (n=28; 72 percent), the group with moderate to severe hearing difficulty reported the highest rate for community travel four or more days per week (92 percent compared to 83 percent for no hearing difficulty and 72 percent for minor hearing difficulty). Additionally, all of the participants (n=7) who could be considered as having the highest degree of disability for community mobility (combined moderate to severe hearing difficulty and profound vision difficulty), indicated that they independently get out in their community at least four to six days a week. There were no notable differences in the impact of hearing difficulty on mobility activity frequency when comparing the older and younger adult groups.

Mobility Activity Frequency	***Hearing Function Level***			***Total***
	No difficulty	*Minor difficulty*	*Moderate to severe difficulty/ hard of hearing*	
2-3 days per week	10.00	5.00	1.00	16.00
	62.50%	31.25%	6.25%	100%
	16.67%	27.78%	8.33%	17.78%
	11.11%	5.56%	1.11%	17.78%
4-6 days per week	22.00	7.00	6.00	35.00
	62.86%	20.00%	17.14%	100%
	36.67%	38.89%	50.00%	38.89%
	24.44%	7.78%	6.67%	38.89%
Every day	28.00	6.00	5.00	39.00
	71.79%	15.38%	12.82%	100%
	46.67%	33.33%	41.67%	43.33%
	31.11%	6.67%	5.56%	43.33%
Total	60.00	18.00	12.00	90.00
	66.67%	20.00%	13.33%	100%
	100%	100%	100%	100%
	66.67%	20.00%	13.33%	100%

Table 5. Association between mobility activity frequency and reported hearing function level. Numbers in columns represent count, row %, column %, total %.



	2-3 days	4-6 days	Every day
YA no difficulty	3	9	9
YA minor	0	1	2
YA moderate to severe	1	1	0
OA no difficulty	7	13	19
OA minor	5	6	4
OA moderate to severe	0	5	5

Figure 5. Graph indicating the reported frequency of community mobility according to level of hearing difficulty.

4.2.5 Methods Used for Community Mobility

We collected information about participants' use of technologies and strategies for community mobility through a series of questions that started with an initial inventory of their travel assistance methods. The list of travel assistance methods was derived from the interviews reported on in section 3 (Interviews) and the researcher's previous work. Participants reviewed the list and selected all the options they use, including an "Other" choice with a write-in requirement. The responses from this question were used to pre-populate data for three follow up questions about frequency of use and method preferences in familiar and unfamiliar settings. Therefore, only the travel assistance method(s) reportedly used appeared in the ensuing questions about frequency of use and preferences. Generally, "piping" values from one survey question to another is a strategy for reusing responses for a more customized feel or shrinking a list of options to only those that are relevant for subsequent questions. The particular benefit of piping for the participants in this survey was reducing the fatigue associated with magnification use or listening to multiple long lists via screen reader or human assistance.

19. What methods of travel assistance do you use? Choose all options that apply to you.

- ☐ White cane
- ☐ Human guide
- ☐ Guide dog
- ☐ Echolocation
- ☐ Listening to familiar sounds
- ☐ Smartphone or tablet app
- ☐ GPS device (not smartphone or tablet app)
- ☐ Sonar device
- ☐ Crosswalks that talk, beep, chirp, or make other sounds
- ☐ Asking other people that I pass
- ☐ Other - Write In (Required)

Figure 6. Survey Question 19. Checkbox style question to identify the methods of travel assistance used.

Each travel assistance method was reportedly used by at least one participant and six of the methods (i.e., white cane, listening to familiar sounds, crosswalks that make sounds, human guide, asking other people, and smartphone or tablet app) were used by more than half of the participants. The white cane was used by the most people (n=78), whereas sonar was used by the fewest (n=1). Other methods used by participants, but not represented in the list included position of sun for direction of travel, mental map, landmarks that can be felt such as hedges or textured curbs, scent information, route planning ahead of time, and pattern recognition.

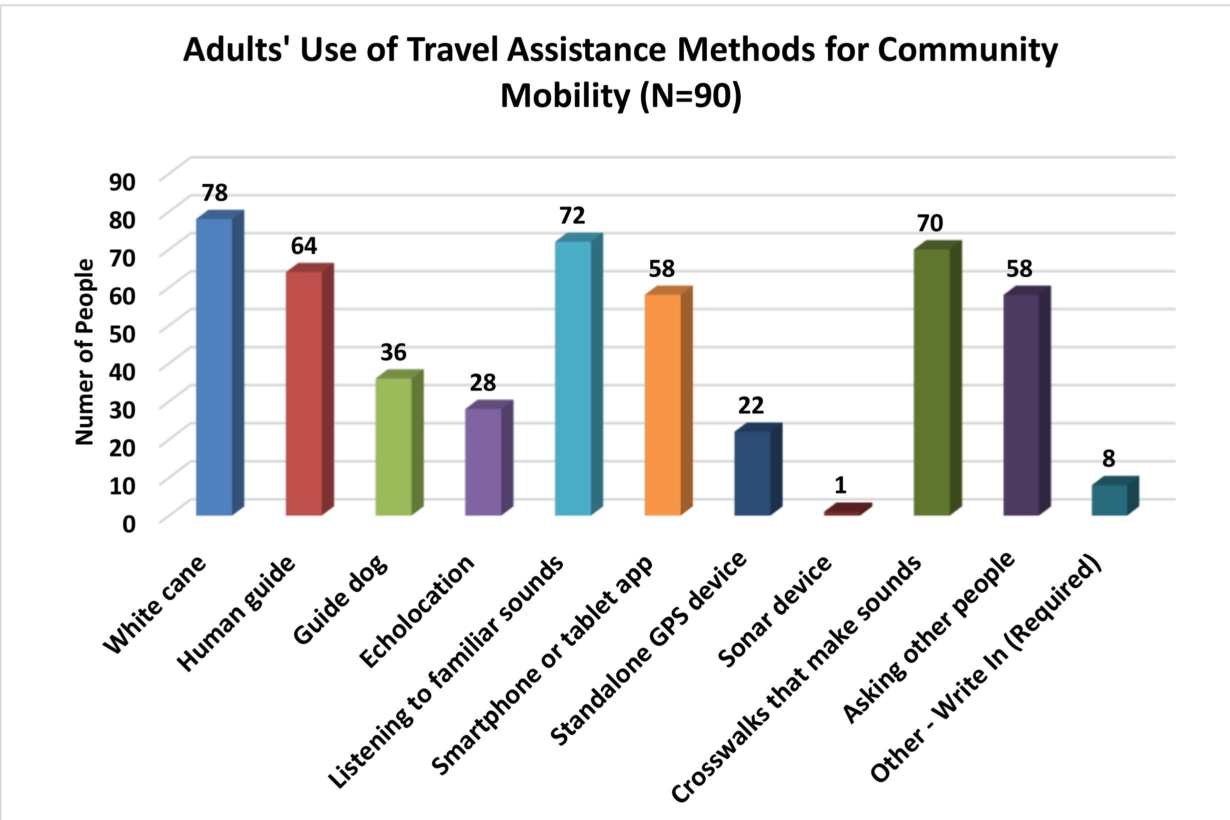


Figure 7. Travel Assistance Methods Used.

In examining method use according to participants' age, vision difficulty, and hearing difficulty, there were some important differences. The greatest difference (but not statistically significant) in reported use based on age can be seen with echolocation – where 46 percent (n=12) of adults younger than 50 used the method compared to only 25 percent (n=16) for those who were 50 years or older. Use of a standalone GPS device also had a noticeable difference between older (30 percent; n=19) and younger adults (12 percent, n=3).

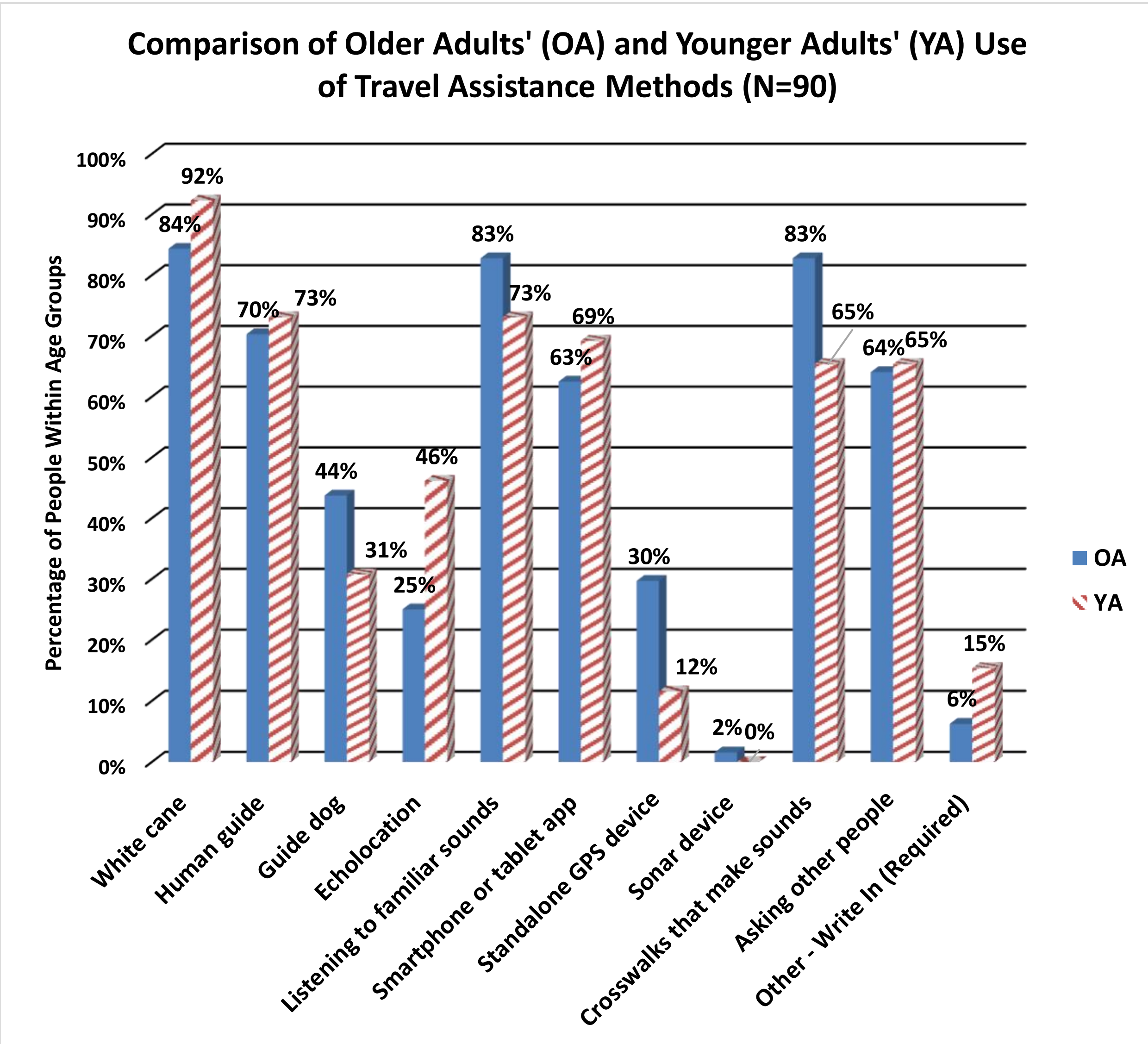


Figure 8. Age Comparison of Method Use.

For reported level of vision difficulty, there was a higher percentage of users across each method who said they had profound difficulty seeing or were blind. A chi-square test of independence was performed to examine the relation between level of vision difficulty and each of the methods. The relation between these variables was significant at $p < .01$for five of the methods. Adults with greater vision difficulty were more likely to use the following methods compared to adults with less vision difficulty: human guide, X^2 (1, N = 90) = 10.18, p = .001; echolocation, X^2 (1, N = 90) = 7.92, p = .005; smartphone or tablet app, X^2 (1, N = 90) = 10.37, p = .001; and asking other people, X^2 (1, N = 90) = 7.41, p = .006.

Use of Travel Assistance Methods by Vision Difficulty		
	VD2 n=24	**VD3** n=66
White cane	83.3%	87.9%
Human guide	45.8%	80.3%
Guide dog	20.8%	47.0%
Echolocation	8.3%	39.4%
Listening to familiar sounds	66.7%	84.8%
Smartphone or tablet app	37.5%	74.2%
Standalone GPS device	12.5%	28.8%
Sonar device	0.0%	1.5%
Crosswalks that make sounds	75.0%	78.8%
Asking other people	41.7%	72.7%
Other - Write In (Required)	16.7%	6.1%

Table 6. Method Use According to Vision Difficulty

For level of reported hearing difficulty, chi-square testing did not reveal any significance. However, there were several interesting trends in the methods used depending on whether the participant had any level of hearing difficulty. Echolocation and listening to familiar sounds are two methods that depend greatly on a person's hearing, yet cannot be adjusted by the person to make them easier to hear. Both of these methods showed a higher rate of use in participants without hearing difficulty compared to those with hearing difficulty. For echolocation, 35 percent (n=21) had no hearing difficulty and 23 percent (n=7) had at least a mild hearing difficulty. Listening for familiar sounds had 85 percent (n=51) without hearing difficulty and 71 percent (n=21) with at least a mild hearing difficulty. Smartphone or tablet apps, which can be adjusted by the person to be easier to hear, presented a similar decline in use across the level of hearing difficulty with 72 percent (n=43) reporting no hearing difficulty and 50 percent reported some degree of hearing difficulty (n=15). The two methods requiring human assistance (i.e., human guide and asking other people I pass), also both had a decrease in use based on hearing difficulty. It seems reasonable that participants with moderate to severe hearing difficulty (n=5; 42 percent) might be less likely to ask other people for assistance compared to those without hearing difficulty (n=43; 72 percent) given that their hearing difficulty could make it harder for them to communicate with someone they pass on the street. However, it is unclear why a human guide who could provide physical assistance was slightly less popular with participants with hearing difficulty (n=19; 63 percent) compared to those without (n=45; 75 percent).

Use of Travel Assistance Methods by Hearing Difficulty			
	HD0 n=60	**HD1** n=18	**HD2** n=12
White cane	83.3%	94.4%	91.7%
Human guide	75.0%	66.7%	58.3%
Guide dog	38.3%	38.9%	50.0%
Echolocation	35.0%	22.2%	25.0%
Listening to familiar sounds	85.0%	77.8%	58.3%
Smartphone or tablet app	71.7%	50.0%	50.0%
Standalone GPS device	25.0%	22.2%	25.0%
Sonar device	0.0%	5.6%	0.0%
Crosswalks that make sounds	80.0%	72.2%	75.0%
Asking other people I pass	71.7%	55.6%	41.7%
Other - Write In (Required)	8.3%	11.1%	8.3%

Table 7.Methods Use According to Hearing Difficulty

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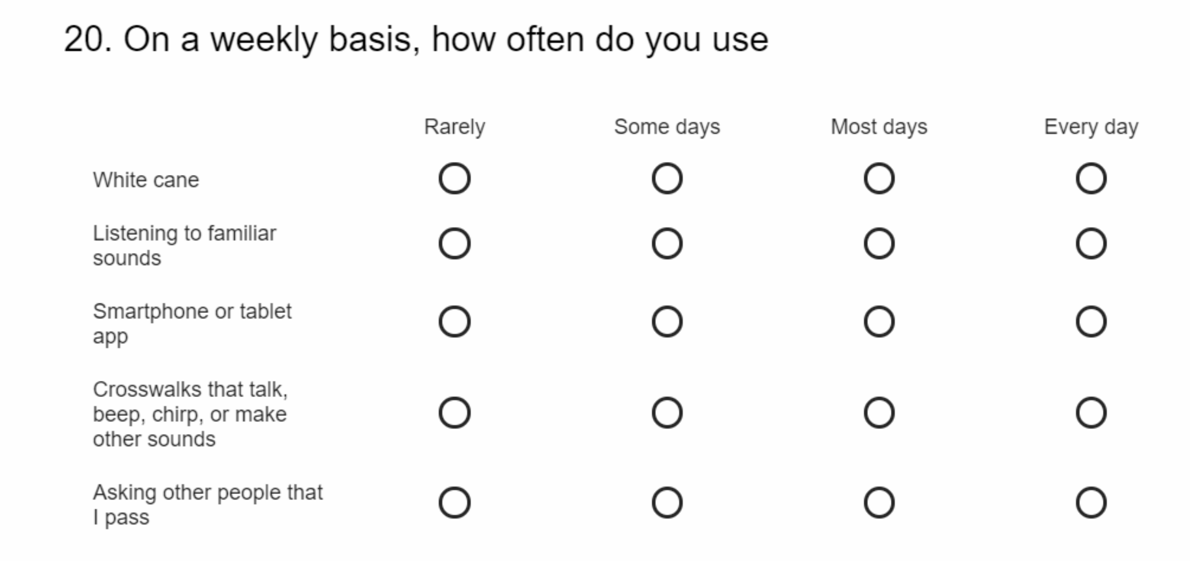
4.2.6 Frequency of Use for Methods

The follow up question about the frequency of use was presented in a row and column format, with the rows representing the participant's previously selected methods (piped in from question #19) and the columns displayed as frequency of use (i.e., rarely, some days, most days, and every day). If the participant had selected the "Other" option in the previous question, their write-in response was piped into its own row. This question was not required in the event that participants had difficulty accessing or understanding the table (row/column) format of the question.



20. On a weekly basis, how often do you use

	Rarely	Some days	Most days	Every day
White cane	○	○	○	○
Listening to familiar sounds	○	○	○	○
Smartphone or tablet app	○	○	○	○
Crosswalks that talk, beep, chirp, or make other sounds	○	○	○	○
Asking other people that I pass	○	○	○	○

Figure 9. Survey Question 20. Row and Column style question to identify the frequency of use for specified methods for community mobility.

Although the method used by the greatest number of participants (n=74; 85 percent) was the white cane, it was not the method used most on a daily basis. Only 58 percent (n=42 out of 74) of white cane users reported using their canes on a daily basis compared to 83 percent (n=55 out of 66) of participants who listened for familiar sounds every day. Crosswalks with sounds, which are the third most used method (n=64), had fair distribution across the frequency of use range with 17.2 percent (n=11) for rarely, 29.7 percent (n=19) for some days, 29.7 percent (n=19) for most days, and 23.4 percent (n=15) for every day. This would be expected because the availability of crosswalks isn't guaranteed unless a person takes the same route most or every day. Leveraging other people as human guides or assistance along the way (asking other people) were commonly used methods that participants largely engaged in less frequently during the week. Smartphones or tablet apps were also popular among participants (n=55; 63.2 percent), but used less frequently as a majority reported they only used these some days (n=31; 56.4 percent) or rarely (12.7 percent). There was no major impact of hearing difficulties on frequency of use for mobility methods.

Adults' Frequency of Use for Travel Assistance Methods (n=87)

	Rarely	Some Days	Most Days	Every Day	Total # of Responses
White cane	13	7	12	42	74
Human guide	14	37	5	3	59
Guide dog	1	1	8	25	35
Echolocation	1	5	6	12	24
Listening to familiar sounds	0	2	9	55	66
Smartphone or tablet app	7	31	8	9	55
Standalone GPS device	5	9	4	2	20
Sonar device	0	1	0	0	1
Crosswalks that make sounds	11	19	19	15	64
Asking other people	9	25	16	6	56
Other - Write In (Required)	0	2	3	3	8

Table 8.Adults' Frequency of Use for Travel Assistance Methods. The rows indicate methods and the columns indicate the frequency of use. Color shading represents quantity with a red to green progression indicating lower to higher amounts.

4.2.7 Method Preferences in Familiar and Unfamiliar Areas

Participants were asked about their preferences for method when traveling in familiar and unfamiliar areas. This is related to frequency of use, but is distinct in that the preferences that people have for using a particular method given their level of familiarity with the area is likely based on knowledge of the area, and feelings of confidence with independent mobility and the method(s) they use. The survey question (see Figure X) for eliciting this information also leveraged the piped in responses from the previous question (#19) that required them to identify the methods they use. These responses were listed as check boxes so that participants could choose more than one method. If the participant had selected the “Other” option in the question #19, their write-in response was also piped in.

21. When traveling in familiar areas, what method or methods do you most prefer?

- ☐ White cane
- ☐ Listening to familiar sounds
- ☐ Smartphone or tablet app
- ☐ Crosswalks that talk, beep, chirp, or make other sounds
- ☐ Asking other people that I pass

Figure 10. Survey Question on Method Preference

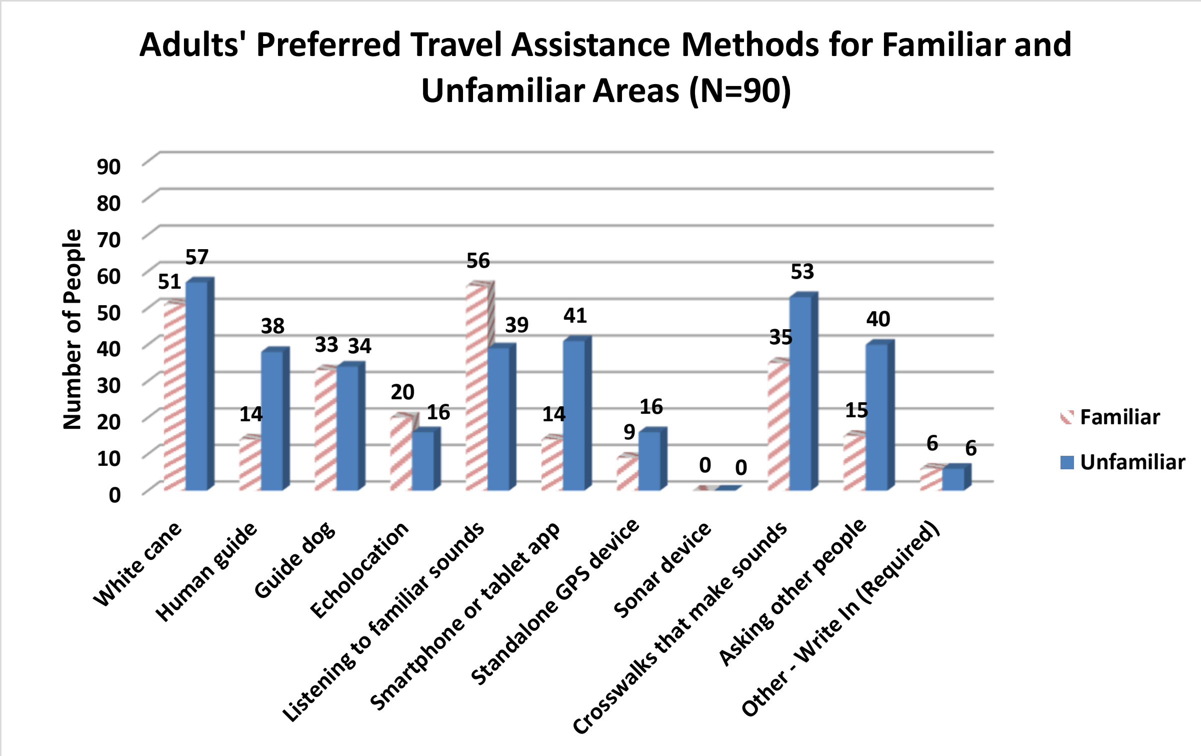


Figure 11. Preferred Methods for Familiar and Unfamiliar Areas

Overall, there were more methods listed for unfamiliar settings (n=340) compared to familiar settings (n=253). The white cane was the most used method for unfamiliar settings (n=57), while also being the second most used method for familiar settings (n=51). The most popular method for familiar settings was listening to familiar sounds (n=56). The methods with the greatest disparity between familiar and unfamiliar choices were human guide (difference of 24), smartphone or tablet app (difference of 27), and asking other people (difference of 25). These three were all preferred by more people in unfamiliar settings versus familiar. There were no statistically significant relationships among vision or hearing difficulty and method preferences for familiar and unfamiliar areas.

Adults' Preferences for Travel Assistance Methods According to Vision Difficulty (VD) and Hearing Difficulty (HD) (N=90)

***percentages are based on total number of people within each VD/HD group**

	Familiarity	VD2 n=24	VD3 n=66	HD0 n=60	HD1 n=18	HD2 n=12
White cane	Familiar	54.2%	57.6%	58.3%	66.7%	33.3%
	Unfamiliar	62.5%	63.6%	67%	50.0%	66.7%
Human guide	Familiar	8.3%	18%	18.3%	11.1%	8%
	Unfamiliar	29.2%	47.0%	46.7%	27.8%	41.7%
Guide dog	Familiar	16.7%	43.9%	36.7%	33.3%	41.7%
	Unfamiliar	16.7%	43.9%	38.3%	33.3%	33.3%
Echolocation	Familiar	4.2%	28.8%	23.3%	22.2%	16.7%
	Unfamiliar	0%	24%	18.3%	17%	16.7%
Listening to familiar sounds	Familiar	54.2%	65.2%	65.0%	61.1%	50.0%
	Unfamiliar	29.2%	48.5%	51.7%	22%	33.3%
Smartphone or tablet app	Familiar	0%	21%	16.7%	22.2%	0%
	Unfamiliar	29.2%	51.5%	55.0%	27.8%	25.0%
Standalone GPS device	Familiar	0%	14%	10.0%	5.6%	16.7%
	Unfamiliar	12.5%	19.7%	21.7%	6%	16.7%
Sonar device	Familiar	0%	0%	0%	0%	0%
	Unfamiliar	0%	0%	0%	0%	0%
Crosswalks that make sounds	Familiar	33.3%	40.9%	40.0%	22.2%	58.3%
	Unfamiliar	50.0%	62.1%	60%	56%	58.3%
Asking other people	Familiar	16.7%	16.7%	16.7%	16.7%	17%
	Unfamiliar	33.3%	51.5%	55.0%	28%	33.3%
Other - Write In (Required)	Familiar	8.3%	6%	8.3%	0%	8%
	Unfamiliar	25.0%	4.5%	10.0%	11%	8%

Table 9. Method Preferences According to Vision and Hearing Difficulty.

4.2.8 Problems Hearing or Understanding Methods

Participants were asked about methods they have tried, but had difficulty hearing or understanding. All methods had at least a few participants reporting problems. Surprisingly, twenty-seven participants (30 percent) indicated that they did not have problems with any of the listed methods (see Figure X). The top two most problematic methods were echolocation (n=35; 28 percent) and smartphone or tablet apps (n=23; 26 percent). The methods with the fewest participants reporting difficulties were guide dog (n=4; 4 percent), human guide (n=8; 9 percent), and white cane (n=10; 11 percent). Each of the other methods had reportedly been problematic for 18 to 20 percent of the participants.

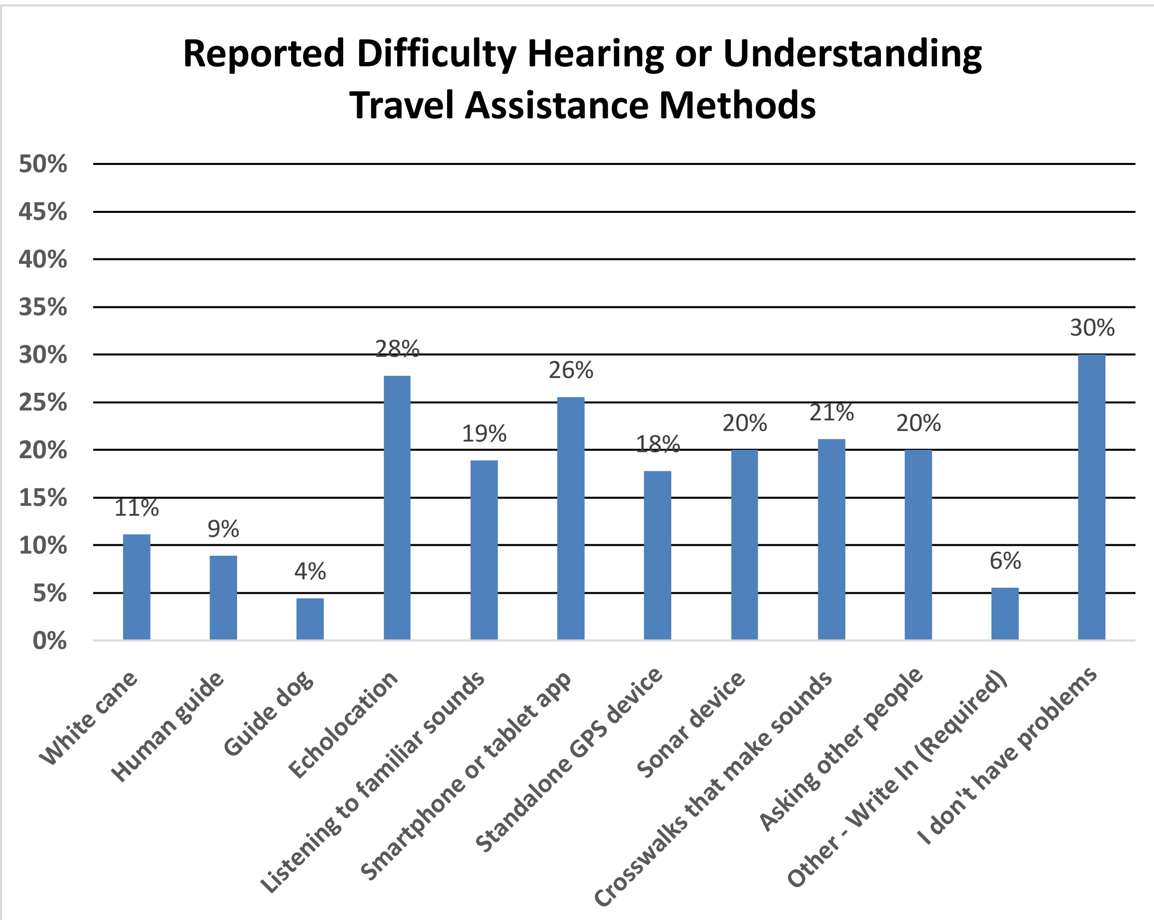


Figure 12. Difficulty Hearing or Understanding Methods

While there were not any statistically significant differences between the older adults and younger adults, there were a few interesting variations to mention. Human guides and crosswalks that make sounds had at least a 14% gap between younger and older adults reporting problems, with younger adults more likely to have problems with these methods (see Figure X). Standalone GPS devices also had a noticeable gap, with 22 percent (n=14) of older adults reporting problems versus 8 percent (n=2) of younger adults. Additionally, more older adults (n=22; 34 percent) compared to younger adults (n=5; 19 percent) reported they did not have any problems with methods.

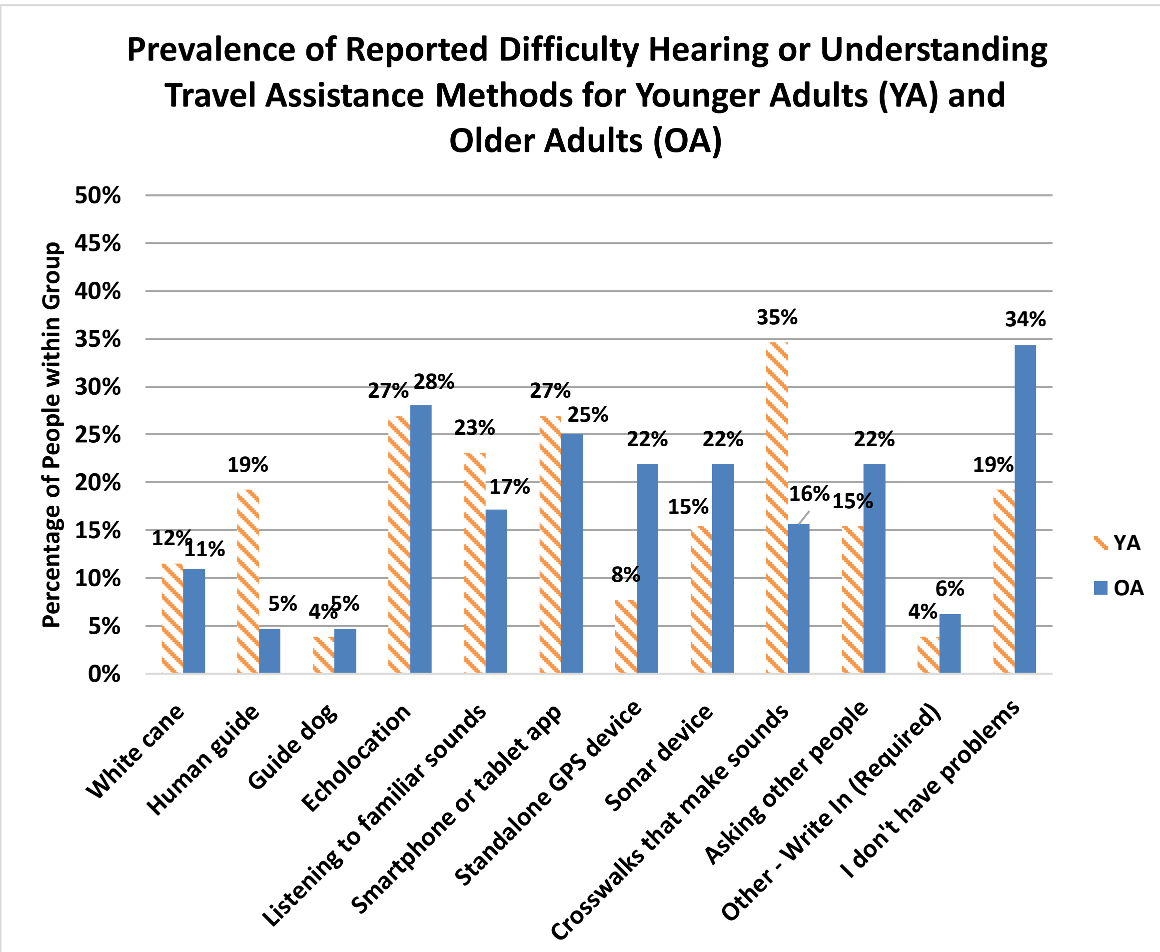


Figure 13. Difficulty Hearing or Understanding Methods According to Age Groups

Reported Difficulty Hearing or Understanding Travel Assistance Methods According to Hearing Difficulty

	HD0 n=60	HD1 n=18	HD2 n=12
White cane	8.3%	16.7%	16.7%
Human guide	8.3%	11.1%	8.3%
Guide dog	6.7%	0.0%	0.0%
Echolocation	25.0%	27.8%	41.7%
Listening to familiar sounds	8.3%	27.8%	58.3%
Smartphone or tablet app	23.3%	38.9%	16.7%
Standalone GPS device	16.7%	27.8%	8.3%
Sonar device	21.7%	16.7%	16.7%
Crosswalks that make sounds	18.3%	27.8%	25.0%
Asking other people	11.7%	27.8%	50.0%
Other - Write In (Required)	1.7%	16.7%	8.3%
I don't have problems	38.3%	16.7%	8.3%

Table 10. Difficulty Hearing or Understanding Method According to Hearing Difficulty

4.2.9 Specific Issues with Methods

Follow up questions were posed to identify specific causes of difficulty with the travel assistance methods that participants had tried, but found hard to use. We did not include follow up questions for human guide, guide dog, and asking other people because these methods were deemed less relevant for our interests in technology development. The follow up questions focused on distinguishing problems that participants reported as resulting from the quality of the target sounds versus interference from surrounding or ambient noise. We recognize that it could be difficult for a person to discern whether difficulty hearing or understanding a sound is due to the design of the sound, quality of a device’s speaker, hearing loss, interfering noise, or a combination of these possibilities. Given the nature of this self-report survey, we would not expect participants to always be able to accurately identify the source(s) of difficulty, so we allowed participants to choose more than one option in identifying the source of problems and we asked further questions to gain additional information. Participants were also asked to provide strategies they used to overcome their difficulties with the method and suggestions to make the methods more effective. There were a few participants who initially indicated difficulty with a method, but did not respond to the follow up questions to further explain their problems. This resulted in 15 (out of 128) data sets for the travel assistance methods.

Feedback about white cane, echolocation, listening to familiar sounds, smartphone or tablet apps, standalone GPS devices, and sonar suggests that a majority of the problems that people have in hearing or understanding these travel assistance methods were related to noise interference from the surrounding environment. This included sounds from traffic, construction, weather, or other external sources. Participants also reported difficulties that they attributed to the perceptual qualities of the target sound. These difficulties are likely due to either poor sound quality coming from the device or a mismatch between the sound and the person's hearing abilities. Each of these travel assistance methods will be discussed separately.

		White Cane n=8	Echolocation n=23	Listening to Familiar Sounds n=17	Sonar n=18	Smartphone or Tablet App n=18	Standalone GPS device n=16
Problems with Target Sounds	Environmental Sounds	3	13	8	N/A	N/A	N/A
	Device Voice	N/A	N/A	N/A	N/A	10	4
	Device Other Sounds	N/A	N/A	N/A	2	6	3
Noise Interference		8	20	17	6	16	15

Table 11. Specific Issues with Methods

White Cane

Eight of the initial 10 participants who suggested they had problems with white canes provided additional details. A majority of these participants reported hearing loss (n=5; 63 percent) and were over 60 years of age (n=5; 63 percent). All participants cited noise interference as a cause for their difficulties. The three participants who indicated problems hearing the sounds coming from cane movement (i.e., touching, sliding, dragging, trailing, tapping) all had hearing loss. Other sources of difficulty that participants mentioned were the cane tip material, uneven surfaces such as brick or gravel, and surface conditions such as water ponding, mud, and debris. One participant mentioned techniques for overcoming problems hearing the white cane sounds including using a "tap-slide technique to give a more sustained sound" and "repeated tapping to enable echolocation through cane." Two other participants commented that adding functionality to the white cane would be unfavorable. One said that it could make a person distracted and the other said that it would add weight and make cane use less efficient.

Echolocation

Specific issues with echolocation were mentioned by 23 of the 25 participants who stated they had problems with the method. These participants were primarily older (n=16; 70 percent), with profound vision loss or blindness (n=17; 74 percent) and no reported hearing difficulty (n=14; 61 percent). Most participants (n=20; 87 percent) indicated that noise interference was a concern and over half (n=13; 57 percent) said that hearing the target sounds was problematic. Additional issues associated with echolocation include lack of formal training, impact of colds or ear infections on the effectiveness of the method, inconsistency or limitations in how the method works for different surfaces and distances, unease about doing it in front of people. Several participants mentioned that to overcome their difficulties they combined echolocation with other methods such as white cane use, using their hands to trail walls or feel other surfaces, and asking people for assistance. Ideas for making echolocation more effective were focused on better training and wearable devices that could amplify the sounds or provide haptic feedback.

Listening for Familiar Sounds

Noise interference was a challenge for all participants (n=17) who had difficulty hearing the familiar ambient sounds they use for mobility. These participants were well distributed across age range (YA n=6; OA n=11), severity of vison impairment (VD2=7; VD3=10), and level of hearing difficulty (HD0 n=5; HD1 n=5; HD3 n=7). Although traffic sounds were predictably referenced as noise interference, participants also said they relied on vehicle noises to navigate parking lots, estimate proximity to intersections, determine the direction of traffic flow, and decide when to cross streets. A few participants asserted that listening for these cues has been made more difficult by quieter cars. Weather was also cited as a noise issue because it can create sustained interference (e.g., rain, wind), abruptly overpower target sounds (e.g., thunder, wind gusts, or sudden downpours), and change the characteristics of target sounds (e.g., rain on surfaces changes the acoustics of the space). Nearly half (n=8; 47 percent) also reported that familiar sounds were hard to hear even in the absence of noise interference. A few participants (n=4) proposed that their diminished hearing abilities caused difficulties with one person stating that their hearing was less reliable because of "getting older", a couple people referencing an inability to determine direction of sound, and another person complaining of "inner ear issues". Spatial designs such as wide and open areas or spaces that created echoes were also mentioned as barriers to effectively hearing familiar sounds. Strategies used by participants to make it easier to hear and understand familiar sounds included: 1) combining with another method (e.g., GPS, human guide or asking a passerby, and trailing with hand); 2) adjustments to their hearing aid: 3) avoiding times when noises are expected (e.g., scheduled lawn service); 4) focusing better on target sounds (e.g., cupping an ear, not engaging in conversation with their walking partner(s); 5) turning the "good ear" toward the sound, actively concentrating); and 6) practicing at home.

Several participants (n=3) suggested that a technology that could describe the environment as they walked might make it easier to leverage familiar sounds for community mobility. Better hearing aids and a device that tunes out or covers up excess noise were other potential solutions mentioned.

Smartphones or Tablets

Most participants who reported difficulty using a smartphone or tablet for mobility purposes provided further detail about the suspected cause of their problems (78 percent; n=18). These participants were largely in the older adult (OA) age group (n=14), had a nearly equal distribution between no hearing difficulty (n=10) and some hearing difficulty (n=8), and were split evenly according to level of vision difficulty. Interference from surrounding noise was the prevailing issue identified by 89 percent of the participants (n=16). Participants also identified difficulties stemming from the device according to problems hearing or understanding the device’s voice output and other non-speech sounds. Although participants were asked about both the main voice and other voices produced by their devices, it is impossible to know whether they could accurately differentiate between these two types of voices and thus, give informed responses. Therefore, participant’s individual responses related to the two types of voices are reported here as a combined single voice option (Device Voice). Fifty-six percent of participants (n=10) reported that voice coming from their device was hard to hear or understand. Complaints about device voices were largely about low volume level or reduced loudness (n=6), poor intelligibility (n=6), or irregular pronunciation of words (n=8). Some participants also found gender or pitch (n=4) and speed (n=1) to be a source of frustration. Conversely, only 33 percent (n=6) responded that the non-speech sounds from their devices were difficult for them to use and cited specific issues with low volume levels (n=3) and poor sound clarity (n=4). Participants also described other limiting factors that impacted device use including: 1) voice software inconsistencies (e.g., loudness levels that change across apps, apps that are not compatible with OS voice software); 2) unreliable access to data service (e.g., spotty Internet coverage, slow data speeds, inaccurate Google maps); and 3) distracting interface (e.g., device sounds interfere with listening to traffic sounds or other useful cues, operating or holding device while walking is unsafe or impedes use of hands for other tasks). A majority of the participants attempt to make the sounds easier to hear or understand by making it louder (n=12), putting their device up to their ear (n=15), or wearing headphones/earphones (n=15). A few participants employed tactile feedback or vibration features to supplement the sound information (28 percent; n=5).

GPS Devices

Most of the participants who experienced problems with standalone GPS devices were in the older adult (OA) age group (n=14; 88 percent). A majority reported a profound vision impairment or blindness (n=11; 69 percent) and had no hearing difficulty (n=10; 63 percent). Noise interference was the dominant issue for participants, with 94 percent (n=15) indicating it was a problem compared to only 25 percent (n=4) who referenced difficulties with the device’s voice output and just 8 percent (n=3) suggesting fault with other sounds made by the device. Four participants described challenges associated with paying attention to the information coming from the device and surrounding environment at the same time. Other barriers included reliability of the device (e.g., stops working or repeats information) and distracting interface (e.g., holding the device impedes use of hands for other tasks). Participants strategies for making the sounds easier to hear or understand include making it louder (n=6), putting the device up to their ear (n=10), or wearing headphones/earphones (n=11). A small number of participants employed tactile feedback or vibration features to supplement the sound information (13 percent;

n=2). Suggestions for improvements to GPS devices were to integrate more haptic information, employ higher quality voice output, and develop a more efficient interface that minimizes the number of steps required for an action.

Sonar Devices

Only ten of the 18 participants who reported difficulties with sonar provided further detail about the cause of their issues. This is the lowest response rate out of all the methods for these follow up questions and suggests that participants may not have been able to articulate their problems with sonar devices or did not have enough experience with a device to understand why it was difficult for them to use. For those who responded, a majority were older (n=7; 70 percent), had no hearing difficulties (n=7; 70 percent), and had profound vision impairment or were blind (n=9; 90 percent). Similar to all the methods previously discussed, noise interference was the issue cited by a majority of participants (n=6). Two participants said that the sounds from the device were hard to hear. One attributed this to volume level (too loud and too quiet) and the other referenced frequency (pitch). Other difficulties associated with the device output focused on being able to process and make sense of the sonar information. Six participants provided comments indicating problems such as “too much data too quickly”, “confusing”, “hard to interpret”, “I get better info from other sources”, “the sound is irritating”, and “too much info”. Supplementing with vibration (n=2) and turning up the volume (n=1) were the only strategies participants reportedly used to make the sounds easier to hear or understand. Suggestions for improvement to sonar devices were limited to designing a system that is easier to control or customize in the moment and developing a watch-based interface.

Crosswalks with Sound Output

A majority of the participants who reported difficulties with crosswalks gave additional feedback (n=17; 89 percent). Most had profound vision impairment or were blind (n=12; 71 percent) and had no hearing difficulties (n=10; 59 percent). Slightly more than half (n=9; 53 percent) were in the older age (OA) group. The most common issue was that sounds made by crosswalk technology (e.g., spoken street names and non-speech sounds such as chirps, beeps, cuckoos, ticking, etc.) are difficult to hear or understand. Nearly half (n=8; 47 percent) of this participant subgroup reported problems hearing non-speech sounds, 29 percent (n=5) said spoken street names are difficult to understand, and 18 percent (n=3) were uncertain about the meaning of the non-speech sounds. One person elaborated that even within the same city there can be a variety of crosswalk sounds leading to inconsistency and confusion. Other reported issues that might be related to sound-based crosswalk technology, but could also include problems with visual and tactile elements were identifying the starting point of the crosswalk (n=3), determining the time remaining for safe crossing (n=7), and estimating the distance yet to cross (n=3). Activating crosswalk technology was identified as a potential concern by a few participants (n=3). They explained that some crosswalk buttons are difficult to locate on the pole, are far away from the start of the crosswalk, and have locator tones that are hard to hear. Several participants (n=4) also mentioned that noise interference from traffic, weather, and construction affected their reliance on crosswalk sounds. Participants made suggestions that addressed all aspects of crosswalk interactions from the activation button, to digital displays, to crosswalk pathways, to the sounds. They want crosswalk paths made more obvious through raised domes, brighter paint, or built-in flashing lights. Several advised that crosswalk sounds should be louder than traffic or adjust according to ambient noise levels. Improved intelligibility of commands or street names and larger digital signs were also recommended. A common thread among their suggestions was to develop informed and consistent design standards for crosswalks that would be enforceable. The United States does not currently have legislation or enforceable policies that require installation of accessible pedestrian signals (APS). There is useful design guidance for APS in the Manual on Uniform Traffic Control Devices from the Federal Highway Administration (https://mutcd.fhwa.dot.gov/htm/2009/part4/part4e.htm) and carried forth in the US Access Board's Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way from 2011 (https://www.access-board.gov/guidelines-and-standards/streets-sidewalks/public-rights-of-way/proposed-rights-of-way-guidelines). However, without adoption by the US Department of Justice, local governments develop their own requirements for APS installation leading to the less effective and inconsistent designs mentioned by participants.

4.3 Discussion

Older individuals who have vision and hearing impairments are more likely to have difficulty with activities outside of the home (community mobility) than their peers with neither or only one of these sensory impairments (Wahl, et al, 2013). This survey represents the first quantitative data about community mobility and the associated issues with the use of assistive technologies and strategies. As such, it generates interesting findings for potential avenues of more in-depth investigation.

Getting out in the community provides a variety of auditory environments with multiple, complicated streams of important and distracting sounds, sometimes coming from the same source. While this rich complexity can challenge most people's orientation and mobility skills, one could expect that a person with sensory loss might have serious difficulty with independent travel in their communities even with assistive technologies and strategies. The results from this survey show that adults with vision impairments who get out in the community leverage a variety of technologies and strategies for mobility assistance.

5. Study 3: Interviews on Mobility Confidence

Phone interviews were conducted to collect in-depth information about the difficulties related to competing noise or distracting sounds and the need for enhanced or focused hearing options. We were specifically interested in how confidence shapes and is shaped by an individual's perceptions and experiences with technologies and strategies during independent community mobility. These interviews were approved through the Georgia Tech Institutional Review Board prior to the start of the work.

5.1 Methods

5.1.1 Participants

Four adults (2 male and 2 female) with self-reported long-standing vision impairment of at least 10 years participated in this study (Age range: 32-65 years; Mean age: 54.5 years). To be eligible for this study, participants had to be fluent in English, be age 18 years or older, have had a vision impairment for at least five years, experience hearing difficulties, and use sound-based compensatory strategies and technologies to independently get around in their communities multiple times during the week. Eligible participants were screened by phone prior to selection to ensure that they met study criteria. Screening questions included brief details about duration of vision impairment, nature of hearing difficulties, and personal and public sound-based technology use during community mobility.

5.1.2 Materials

The Interview Guide was internally created to guide researchers through a semi-structured interview. Questions were constrained to an individual's confidence during community mobility activity including what confidence meant to the participant, what makes them feel confident, the role of technology and environmental sounds in their confidence, and strategies they had developed to support confidence.

5.1.3 Procedures

Participants received the study consent document via email prior to the phone interview so they could review it according to their visual needs and prepare any questions. Before the start of the phone interview, the researcher reviewed the consent document with the participant and answered questions before requesting them to verbally consent.

5.2 Results

Findings indicate that a person's mobility confidence is associated with feeling comfortable with their orientation and wayfinding technologies and strategies in the given context. People prefer a technology/guide dog/human guide that they perceive as accurate, reliable, and trustworthy. They were more confident with familiar places/routes and reported that planning ahead or problem solving could boost or support feelings of confidence. Loss of or less confidence happens when the situation is unfamiliar, there is a change in routine, or there is some type of deviation from the norm. Environmental sounds that are important for them to perceive and analyze for orientation and navigation include traffic characteristics (e.g., presence of vehicle noise, direction of travel), auditory landmarks, and crosswalks. Transitory noises like sirens, thunder, or construction often mask important/useful sounds. Rain and wind also have an impact (sometimes by competing directly and other times by changing the quality of important sounds).

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Appendix A –Travel Assistance Methods According to Vision and Hearing Difficulty

Use of Travel Assistance Methods According to Vision Difficulty (VD) and Hearing Difficulty (HD) Levels *percentages are based on total number of people within each VD/HD group						
	VD2/ HD0 (n=13)	VD2/ HD1 (n=6)	VD2/ HD2 (n=5)	VD3/ HL0 (n=47)	VD3/ HD1 (n=12)	VD3/ HD2 (n=7)
White cane	76.9%	83.3%	100%	85.1%	100%	85.7%
Human guide	38.5%	50%	60%	85.1%	75%	57.1%
Guide dog	23.1%	16.7%	20%	42.6%	50%	71.4%
Echolocation	15.4%	0%	0%	40.4%	33.3%	42.9%
Listening to familiar sounds	69.2%	83.3%	40%	89.4%	75%	71.4%
Smartphone or tablet app	38.5%	16.7%	60%	80.9%	66.7%	42.8%
Standalone GPS device	15.4%	16.7%	0%	27.7%	25%	42.8%
Sonar device	0%	0%	0%	0%	8.3%	0%
Crosswalks that make sounds	69.2%	83.3%	80%	83%	66.7%	71.4%
Asking other people	38.5%	50%	40%	80.9%	58.3%	42.9%
Other - Write In (Required)	7.7%	33.3%	20%	8.5%	0%	0%

Appendix B –Frequency of Use According to Hearing Difficulty

Adults' Frequency of Use for Travel Assistance Methods According to Hearing Difficulty (n=87)

	Level of Hearing Difficulty	Rarely	Some Days	Most Days	Every Day	# Participants within Group
White cane	HD0	10.4%	10.4%	16.7%	62.5%	48
	HD1	23.5%	0.0%	17.6%	58.8%	17
	HD2	44.4%	22.2%	11.1%	22.2%	9
Human guide	HD0	23.8%	61.9%	9.5%	4.8%	42
	HD1	36.4%	45.5%	9.1%	9.1%	11
	HD2	0.0%	100%	0.0%	0.0%	6
Guide dog	HD0	0.0%	4.5%	18.2%	77.3%	22
	HD1	0.0%	0.0%	42.9%	57.1%	7
	HD2	16.7%	0.0%	16.7%	66.7%	6
Echolocation	HD0	5.3%	26.3%	21.1%	47.4%	19
	HD1	0%	0.0%	33.3%	66.7%	3
	HD2	0%	0.0%	50.0%	50.0%	2
Listening to familiar sounds	HD0	0%	4.3%	12.8%	83.0%	47
	HD1	0%	0.0%	15.4%	84.6%	13
	HD2	0%	0.0%	16.7%	83.3%	6
Smartphone or tablet app	HD0	9.8%	65.9%	12.2%	12.2%	41
	HD1	25%	25%	12.5%	37.5%	8
	HD2	16.7%	33.3%	33.3%	16.7%	6
Standalone GPS device	HD0	28.6%	50%	14.3%	7.1%	14
	HD1	25%	50%	25%	0%	4
	HD2	0%	0%	50%	50%	2
Sonar device	HD0	0%	0%	0%	0%	0
	HD1	0%	100%	0%	0%	1
	HD2	0%	0%	0%	0%	0
Crosswalks that make sounds	HD0	20.0%	33.3%	24.4%	22.2%	45
	HD1	18.2%	27.3%	36.4%	18.2%	11
	HD2	0.0%	12.5%	50.0%	37.5%	8
Asking other people	HD0	26.2%	52.4%	14.3%	7.1%	42
	HD1	44.4%	44.4%	11.1%	0.0%	9
	HD2	0.0%	40.0%	40.0%	20.0%	5
Other - Write In (Required)	HD0	0.0%	20.0%	40.0%	40.0%	5
	HD1	0.0%	50.0%	50.0%	0.0%	2
	HD2	0.0%	0.0%	0.0%	100%	1

Appendix C – Preferences for Travel Assistance Methods According to Vision and Hearing Difficulty (HD)

Adults' Preferences for Travel Assistance Methods According to Vision Difficulty (VD) and Hearing Difficulty (HD) (n=90)

*percentages are based on total number of people within each VD/HD group

	Familiarity	VD2/ HD0 (n=13)	VD2/ HD1 (n=6)	VD2/ HD2 (n=5)	VD3/ HL0 (n=47)	VD3/ HD1 (n=12)	VD3/ HD2 (n=7)
White cane	Familiar	53.8%	50%	60%	59.6%	75%	14.3%
	Unfamiliar	69.2%	16.7%	100%	66%	66.7%	42.9%
Human guide	Familiar	7.7%	0%	20%	21.3%	16.7%	0%
	Unfamiliar	30.8%	16.7%	40%	51.1%	33.3%	42.9%
Guide dog	Familiar	23.1%	16.7%	0%	40.4%	41.7%	71.4%
	Unfamiliar	23.1%	16.7%	0%	42.6%	41.7%	57.1%
Echolocation	Familiar	7.7%	0.0%	0%	27.7%	33.3%	28.6%
	Unfamiliar	0%	0%	0%	23.4%	25%	28.6%
Listening to familiar sounds	Familiar	53.8%	66.7%	40%	68.1%	58.3%	57.1%
	Unfamiliar	38.5%	16.7%	20%	55.3%	25%	42.9%
Smartphone or tablet app	Familiar	0%	0%	0%	21.3%	33.3%	0%
	Unfamiliar	38.5%	0.0%	40%	59.6%	41.7%	14.3%
Standalone GPS device	Familiar	0%	0%	0%	12.8%	8.3%	28.6%
	Unfamiliar	15.4%	16.7%	0%	23.4%	0%	28.6%
Sonar device	Familiar	0%	0%	0%	0%	0%	0%
	Unfamiliar	0%	0%	0%	0%	0%	0%
Crosswalks that make sounds	Familiar	23.1%	16.7%	80%	44.7%	25.0%	42.9%
	Unfamiliar	38.5%	66.7%	60%	66%	50%	57.1%
Asking other people	Familiar	7.7%	16.7%	40%	19.1%	16.7%	0%
	Unfamiliar	38.5%	33.3%	20%	59.6%	25%	42.9%
Other - Write In (Required)	Familiar	7.7%	0%	20%	8.5%	0%	0%
	Unfamiliar	23.1%	33.3%	20%	6.4%	0%	0%

Appendix D –Travel Assistance Methods by Age

Use of Travel Assistance Methods by Age Groups (N=90)

	18-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75 +
White cane	88.9%	100%	87.5%	100%	100%	91.7%	85.7%	78.6%	60%	66.7%
Human guide	77.8%	100%	62.5%	60%	66.7%	75%	76.2%	71.4%	40%	66.7%
Guide dog	55.6%	0%	25%	20%	33.3%	33.3%	42.9%	64.3%	60%	0%
Echolocation	44.4%	25%	62.5%	40%	11.1%	25%	38.1%	28.6%	0%	0%
Listening to familiar sounds	100%	75%	50%	60%	88.9%	91.7%	81%	85.7%	60%	66.7%
Smartphone or tablet app	55.6%	75%	75%	80%	88.9%	58.3%	76.2%	57.1%	20%	0%
Standalone GPS device	11.1%	0%	12.5%	20%	44.4%	33.3%	23.8%	21.4%	60%	0%
Sonar device	0%	0%	0%	0%	0%	0%	4.8%	0%	0%	0%
Crosswalks that make sounds	88.9%	50%	50%	60%	100%	91.7%	85.7%	85.7%	40%	33.3%
Asking other people	77.8%	75%	50%	60%	66.7%	75%	61.9%	71.4%	40%	33.3%
Other - Write In (Required)	0%	25%	12.5%	40%	11.1%	16.7%	4.8%	0%	0%	0%

Appendix E –Travel Assistance Preferences Based on Familiarity of Area

Comparison of Younger Adults' (YA) and Older Adults' (OA) Travel Assistance Preferences in Familiar and Unfamiliar Areas

Percentages are derived from the number of responses out of the total number within that group (either YA or OA)

	YA Familiar Areas	OA Familiar Areas	YA Unfamiliar Areas	OA Unfamiliar Areas
White cane	53.8%	57.8%	65.4%	62.5%
Human guide	11.5%	17.2%	46.2%	40.6%
Guide dog	26.9%	40.6%	34.6%	39.1%
Echolocation	38.5%	15.6%	26.9%	14.1%
Listening to familiar sounds	65.4%	60.9%	38.5%	45.3%
Smartphone or tablet app	3.8%	20.3%	61.5%	39.1%
Standalone GPS device	0%	14.1%	7.7%	21.9%
Sonar device	0%	0%	0%	0%
Crosswalks that make sounds	26.9%	43.8%	50.0%	62.5%
Asking other people	11.5%	18.8%	53.8%	40.6%
Other - Write In (Required)	15.4%	3.1%	7.7%	6.3%